Accurate Representation of Arbitrary Depth Source Terms in Coastal Wave Prediction Models

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LONG-TERM GOAL

The principal goal of these projects is to improve our understanding of the interactions which govern the spatial and temporal evolution of surface waves in arbitrary depths. This will be accomplished through the Shoaling Waves DRI large-scale field experiment and coordinated wave modeling improvements through the Advanced Wave Predictions Program. The results of these studies will fill Naval Operational wave forecasting needs for accurate and compuationally efficient estimates of the nonlinear wave-wave interaction (S_{nl}) source term for arbitrary depths

SCIENTIFIC OBJECTIVES

The principal objectives of this project is to investigate via numerical means the source term balance in shoaling waves, test newly constructed exact S_{nl} solutions, develop an improved Discrete Interaction Approximation (DIA, Hasselmann et al. 1985, Komen et al 1994), test the approximation method, and ultimately implement this approximation in existing Naval Operational Wave Forecasting methodologies.

APPROACH

The action balance equation has two distinct parts to be solved: spatial changes in the spectrum (i.e. propagation shoaling and refraction) and the temporal changes described by the source terms: atmospheric input (S_{in}), nonlinear wave-wave interaction (S_{nl}), dissipation due to whitecapping (S_{ds}), and wave-bottom effects (S_{wb}). The Shoaling Waves DRI field experiment will attempt to directly measure the atmospheric input, whitecapping, and the effects of wave-bottom interactions. The nonlinear interactions will be directly calculated in this study using the work by Hasselmann and Hasselmann (1981), as well as new methods derived from Resio and Perrie (1991) and solved for arbitrary water depths (Resio et al. 1999). Assessment of the dissipation measurements will be indirectly validated from the source term balance, (again computed from all mechanisms). Exact solutions (using the full dispersion relationship) as well as approximations derived from 3GWAM (Komen et al 1994) will be used for the source term balance (adjusting Sin, S_{ds} and S_{wb} derived from the data).

Prior to the Shoaling Waves field experiment (fall 1999), a series of tests will be conducted using 3GWAM, the Exact NL (Hasselmann and Hasselmann 1981), and the Resio-Tracy (Resio et al. 1999)

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in the proposed measurement domain. Initial testing of the S_{nl} will be evaluated using directional spectra obtained during the DUCK94 experiment (Jensen, 1995).

WORK COMPLETED

A "proof-of-concepts" wave forecasting system was built and implemented during the SandyDuck97 field experiment (in the domain of the Shoaling Waves field experiment). Information generated from this forecast will be used for planning and operational purposes by the Shoaling Waves field experimenters during their Intensive Operation Period. Ultra-high resolution 3GWAM simulations coupled with newly acquired Navy Atmospheric Modeling wind estimates (Coupled Ocean Atmospheric Mesoscale Prediction System, COAMPS) are to be used during the Shoaling Waves field experiment.

Data obtained from the DUCK94 field experiment during a large-scale northeaster producing significant wave heights in excess of 5 m are being assessed. The significant wave height traces for two offshore buoy sites (50 km offshore of the Field Research Facility, separated by about 30 km) show a strong growth cycle and a near uniform wave pattern. This storm can be considered as a classic example of a Atlantic coast northeaster, however the near uniformity in the energy levels are somewhat misleading when the spectral estimates are evaluated.

Academic tests of the arbitrary depth exact S_{nl} were conducted during a meeting with the Advanced Wave Prediction Modeling wave-wave interaction group. A series of spectral tests with varying JONSWAP (Hasselmann et al. 1983) conditions, differing water depths, and one directional shift case were run and evaluated. The Resio-Tracy (R-T) approach results were compared to the Hasselmann, Hasselmann (1981) Exact-NL, (H-H). Results for all tests indicated a very strong agreement between the two methodologies.

Development, testing and implementation of a transect version of the arbitrary depth integration source function is to be performed. The will provide the basis for the investigation toward a new parameterization (similar to the DIA in 3GWAM) in the Navy’s operational wave model better suited for continental shelf applications.

RESULTS

Data obtained from DUCK94 (Figure 1) shows a strong tendency for the significant wave heights in this particular storm to become nearly spatially invariant from offshore wave energy. Time paired observations of the frequency spectra were evaluated for the growth states and presented in Figure 2. There is a net transfer of energy to the forward face of the spectrum during this time with a reduction in the energy levels in the tail, similar in form of the S_{nl}. Calculations derived from two exact methods (Hasselmann and Hasselmann, 1981), as well as the Resio-Tracy (Resio et al. 1998) for a water depth of 40 meters (similar to that in the region between the MidShelf and InnerShelf buoys) display a similar feature (Figure 3). The S_{nl} continues to modify the spectrum over near constant wave regimes to the degree that has been evident in a purely theoretical context. Despite significant differences in the numerical solution methods used in the H-H and R-T approach, the results for this case as well as in all academic tests conducted thus far are quite similar. In addition,

computational requirements for the R-T method is nearly two orders of magnitude less than that for the H-H approach, but remains yet an order of magnitude greater than the DIA used in 3GWAM.

IMPACT

One views the continental shelf as an environment that significantly alters the deepwater directional wave spectrum. The source/sink terms impact their control over changes in the directional spectrum while bathymetric effects attempt to steer the energy dictated by local water depth gradients. What has been found thus far is that the arbitrary depth R-T S_{nl} results emulate historical, baseline results, and provide a significant improvement in computational requirements never before realized. Despite being nearly one order of magnitude slower than the DIA methods, the net gains in the correct estimation of S_{nl}, as well as the basis to make significant strides in replacing the DIA with a far more accurate approximation is now obtainable.

TRANSITIONS

The results derived from this study will be further developed leading toward a transect model (complete with the exact solution to S_{nl}), a complete set of source terms as well as the effects due to changing water depths. This model will be used to calculate near real time source term balances during the Shoaling Waves field experiment. The R-T methods will be incorporated in the 3GWAM architecture for research purposes and evaluated for deep and arbitrary depths. Ultimately, the results from these projects will yield a newly formulated approximation to S_{nl} to be ingested in Naval Operational Wave Forecasting Systems for better approximations of wave conditions over the continental shelf.

RELATED PROJECTS

Listed below are various projects that are directly related to the DRI Shoaling Waves Project and the Advanced Wave Prediction Program.

1. Headquarters, U.S. Army Corps of Engineers: "Modeling the Evolution of Directional Wave Spectra in Arbitrary Water Depths." Development, investigation, validation of modeling technologies and transition the U.S. Army Corps of Engineers district, division offices and in-house Coastal and Hydraulics Laboratory staff for use in the estimation of wave condition in the nearshore domain.

2. Department of Defense HPC Software Support Initiative (CHSSI) in Climate-Weather-Ocean. Migration of 3GWAM to scalable computational environments.

3. Naval Oceanographic Office: Develop, test and transition state-of-the-art wave modeling technologies to the Warfighting Support Center running real-time wave forecasts in direct support of Naval operations worldwide.

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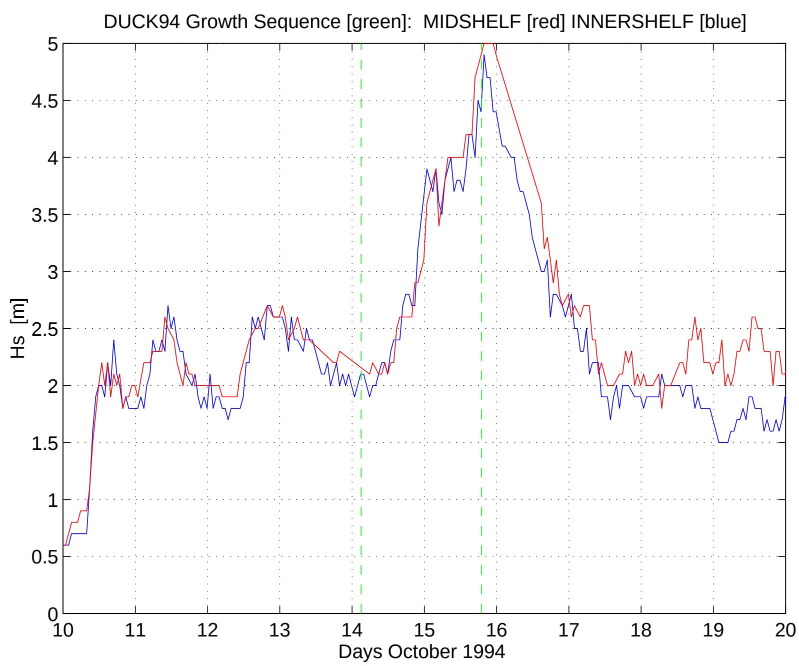

Figure 1. Significant wave height trace for DUCK94.

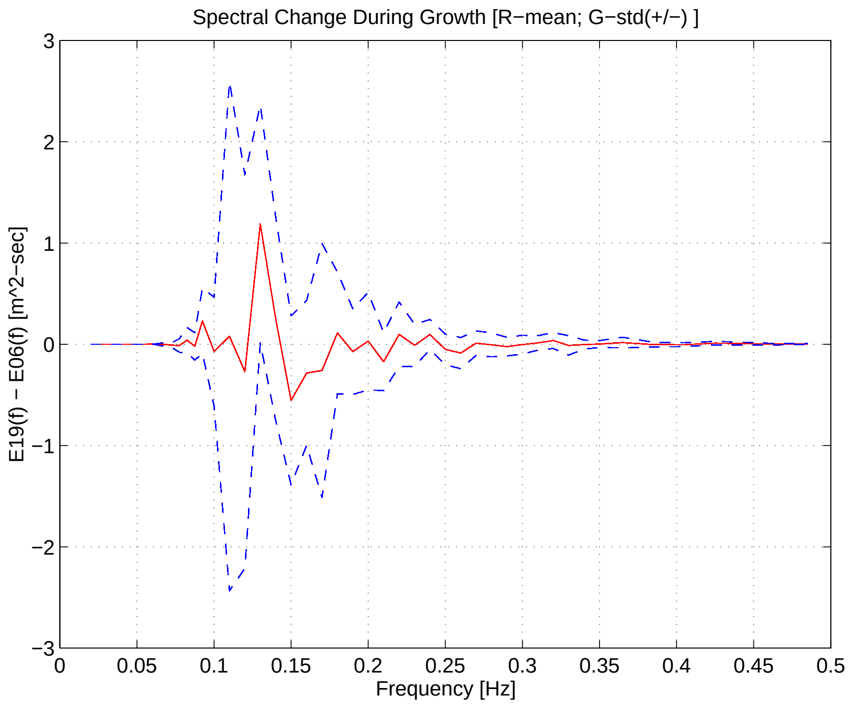

Figure 2. Spatial change in frequency spectra (mean-red, variance-blue)

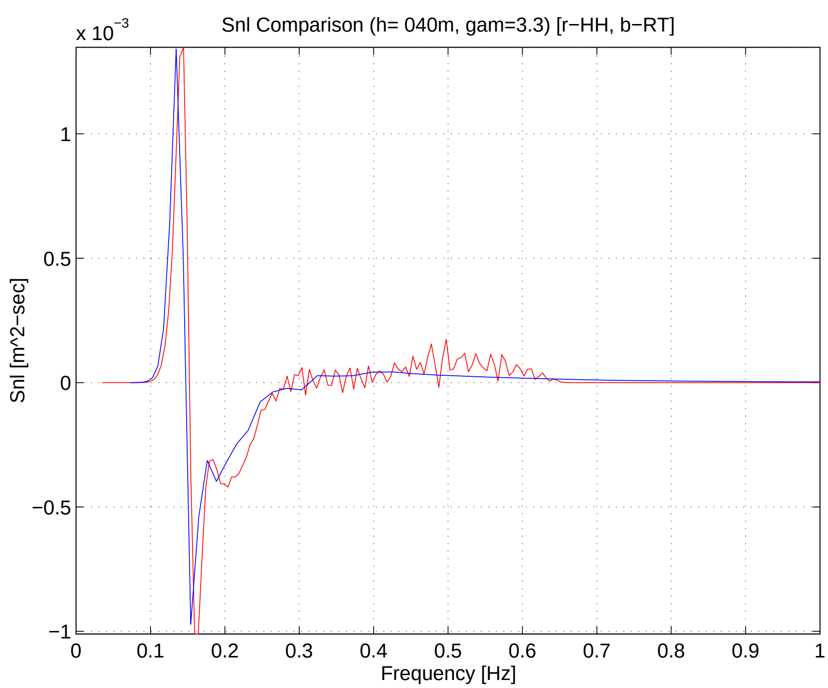

Figure 3. Results of exact calculations using Hasselmann and Hasselmann, and Resio and Tracy.